RECENT NO_x REDUCTION EFFORTS: AN OVERVIEW

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Abstract: *This paper presents an update and overview of recently promulgated nitrogen oxides (NO_x) regulations for large electricity and industrial combustion units, under Title I and Title IV of the Clean Air Act Amendments (CAAA). It evaluates the types of NO_x control technologies installed under both the Acid Rain Program and Ozone Transport Commission (OTC) NO_x Budget Program, and assesses the emissions reductions attained through the application of these control technologies. The sustained improvements in emission rates achieved by NO_x controls, manifest during the first three years of the Acid Rain NO_x Program, have carried over to Phase II of the OTC. Notwithstanding these technical achievements, affected sources rely on emissions averaging and allowance trading to attain cost-effective compliance. Emissions averaging is the most commonly selected compliance option under the Acid Rain NO_x Program, while the volume of economically significant allowance movement under the OTC attests to the degree of compliance flexibility afforded by the cap-and-trade approach.*

I. Introduction

Emissions of NO_x are associated with a variety of environmental concerns including an increase in ground-level ozone, the formation of fine particles in the atmosphere, the development of acid rain, and the acidification of aquatic systems. Such concerns have resulted in a need to reduce these emissions in the United States. Recently, a number of Federal and State regulatory actions have focused on reducing NO_x emissions from fossil fuel-burning, stationary combustion sources. Section II of this paper provides an overview of the regulations affecting NO_x sources, including the Acid Rain NO_x regulations, the OTC NO_x Budget Program, revision of the New Source Performance Standards (NSPS) for NO_x emissions from utility and large industrial sources, and EPA's Ozone Transport rulemakings. Section III then provides an assessment of compliance experience achieved to date under the Acid Rain NO_x Program and the OTC NO_x Budget Program.

II. Regulatory Overview

The Clean Air Act of 1970 established a major role for the Federal government in regulating air quality. The Act was further expanded by amendments in 1977 and, most recently, in 1990. The 1990 Clean Air Act Amendments (CAAA) authorize EPA to establish standards for a number of atmospheric pollutants, including NO_x. Two major portions of the CAAA relevant to stationary source NO_x control are Title I and Title IV. Title I established National Ambient Air Quality Standards (NAAQS) for six criteria pollutants, including ozone. Title IV includes provisions designed to address acid deposition resulting from emissions of NO_x and SO_2 from electric power plants. Table 1 presents an overview of the regulatory actions affecting NO_x sources.

Table 1. Selected NO_x reduction regulations under Title I and IV of the CAAA

	Regulatory Action	Affected Regions	Compliance Date	Control Period	NO_x Reductions
Title I	OTC NO_x Budget Program	12 States & DC: CT, DE, ME, MD, MA, NH, NJ, NY, PA, RI, VT, VA	Phase II: May 1, 1999 Phase III: May 1, 2003	ozone season	246,000 tons in 1999, 322,000 tons in 2003
	NO_x SIP call	22 States & DC: AL, CT, DE, GA, IL, IN, KY, MD, MA, MI, MO, NJ, NY, NC, OH, PA, RI, SC, TN, VA, WV, and WI	May 1, 2003	ozone season	1.1 million tons in 2007

	Regulatory Action	Affected Regions	Compliance Date	Control Period	NO_x Reductions
	Section 126 rule	12 States & DC: DE, IN, KY, MD, MI, NJ, NY, NC, OH, PA, VA, and WV	May 1, 2003	ozone season	510,000 tons in 2007
Title IV	Acid Rain Program	nationwide	Phase I: January 1, 1996 Phase II: January 1, 2000	annual	340,000 tons per year in Phase I, 2.06 million tons/yr in Phase II
	Revised NO_x NSPS	nationwide	July 9, 1997	annual	25,800 tons/yr

1. Title I NO_x Requirements

Title I of the CAAA included provisions designed to address both the continued nonattainment of the existing ozone NAAQS and the transport of air pollutants across State boundaries. These provisions also allow downwind States to petition for tighter controls on upwind States that contribute to their NAAQS nonattainment status. In general, Title I NO_x provisions require areas with an ozone nonattainment region to: (1) require existing major stationary sources to apply reasonably available control technologies (RACT); (2) require new or modified major stationary sources to offset their emissions and install controls representing the lowest achievable emissions rate (LAER); and (3) require each state with an ozone nonattainment region to develop a State Implementation Plan (SIP) that, in some cases, includes reductions in stationary source NO_x emissions beyond those required by the RACT provisions of Title I, if needed to attain the ozone NAAQS.

Ozone Transport Commission (OTC) NO_x Budget Program Section 184 of the CAAA delineated a multi-State ozone transport region (OTR) in the northeast and required specific additional NO_x and VOC controls for all areas in this region. Section 184 also established the OTC for the purpose of assessing the degree of ozone transport in the OTR and recommending strategies to mitigate the interstate transport of pollution. The OTR consists of the States of Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, parts of northern Virginia, and the District of Columbia. The OTR States confirmed that they would implement RACT on major stationary sources of NO_x (Phase I), and agreed to a phased approach for additional controls, beyond RACT, for power plants and other large fuel combustion sources (Phase II and III). This agreement, known as the OTC Memorandum of Understanding (MOU) for stationary source NO_x controls was approved on September 27, 1994. All OTR States, except Virginia, are signatories to the OTC NO_x MOU.

The MOU establishes an emissions trading system to reduce the costs of compliance with the control requirements under Phase II (which began on May 1, 1999) and Phase III (beginning on May 1, 2003). The OTC program caps summer-season (May 1 - September 30) NO_x emissions for all thirteen OTC jurisdictions at approximately 219,000 tons in 1999, and 143,000 tons in 2003, which represent approximately 55 and 70 percent reductions in NO_x, respectively, from the 1990 baseline emission level of 464,898 tons.[1] The actual reductions during the 1999 season, however, reflect participation by only eight of the 13 jurisdictions. This subset includes Connecticut, Delaware, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, and Rhode Island.

NO_x SIP call To address long range transport of ozone, in October 1998, EPA promulgated a rule to limit summer season NO_x emissions in 22 Northeast States and the District of Columbia that the Agency believes are significant contributors to ozone nonattainment in downwind areas (63 FR 57356, October 27, 1998). These States were required to amend their SIPs through a procedure established in Section 110 of the CAAA. EPA finalized a summer-season State NO_x budget (in tons of NO_x) and developed a State implemented and Federally enforced NO_x trading program to provide for emissions trading by certain electric and industrial stationary sources . Each affected State's NO_x budget is based on the application of a population-wide 0.15 lb/mmBtu NO_x emission rate for large electricity generating units (EGUs) and a 60 percent reduction from uncontrolled emissions for large non-EGUs. (Control levels that EPA believes are highly cost effective.) The NO_x SIP call is projected to reduce summer-season NO_x emissions by 1.1 million tons in the affected 22 States and DC. In response to litigation, in May 1999, the U.S. Court of Appeals for the D.C. Circuit issued a ruling that stayed the SIP submission dates required by the NO_x SIP call. In November 1999, the D.C. Circuit heard arguments on the NO_x SIP call; the Court is expected to issue an opinion in the spring of 2000.

Section 126 Petitions In addition to promulgating the NO_x SIP call, EPA responded to petitions filed by eight northeastern States under section 126 of the CAA. The petitions request that EPA make a finding that NO_x emissions from certain major stationary sources significantly contribute to ozone nonattainment problems in the petitioning States. The final section 126 rule requires upwind States to take action to reduce emissions of NO_x that contribute to nonattainment of ozone standards in downwind States (64 FR 28250, May 25, 1999 and 65 FR 2674, January 18, 2000). The findings affect large EGUs and both non-EGU boilers and turbines located in 12 northeast States and the District of Columbia. Like the NO_x SIP call, EPA has finalized a Federal NO_x Budget Trading Program based on the application of a population-wide 0.15 lb/mmBtu NO_x emission rate for large EGUs and a 60 percent reduction from uncontrolled emissions for large non-EGUs. The final Section 126 actions is projected to reduce summer-season NO_x emissions by 510,000 tons in the 12 affected States and D.C. The compliance deadline is May 1, 2003.

2. Title IV NO_x Requirements

Title IV of the CAAA authorized EPA to establish an Acid Rain Program to reduce the adverse effects of acidic deposition on ecosystems, natural resources, materials, visibility, and public health. Emissions of SO_2 and NO_x from the combustion of fossil fuels are important contributors to acidic deposition in the atmosphere. Title IV includes provisions designed to address NO_x emissions from existing power plants.

Acid Rain NO_x Reduction Program Under Title IV of the CAAA, the Acid Rain Program uses a two-phased strategy to achieve the required annual reductions in NO_x emissions. Effective January 1, 1996, Phase I established regulations for Group 1 boilers, which include dry-bottom, wall-fired boilers, and tangentially fired (T-fired) boilers. In Phase II, which began on January 1, 2000, lower emissions limits are set for certain Group 1 boilers, and regulations are established for Group 2 boilers, which include cell-burner, cyclone, wet-bottom wall-fired, and other types of coal-fired boilers. The regulations allow for emissions averaging in which the emissions levels established by EPA are applied to an entire group of boilers owned or operated by a single company.

Beginning January 2000, Phase II of the Acid Rain Program requires annual average emission rates for most Group 1 boilers of 0.46 lb/mmBtu for dry-bottom wall-fired boilers and 0.40 lb/mmBtu for tangentially fired boilers. Some Group 1 boilers are not affected by the Phase II rates and will continue to comply with the Phase I annual average emission rates of 0.50 lb/mmBtu for dry-bottom wall-fired boilers and 0.45 lb/mmBtu for tangentially fired boilers. The Phase II limits are 0.68 lb/mmBtu for cell burners, 0.86 lb/mmBtu for cyclones greater than 155 MWe, 0.84 lb/mmBtu for wet bottom boilers greater than 65 MWe, and 0.80 lb/mmBtu for vertically fired boilers. Phase I compliance results for 1996 show that, from 1990 to 1996, the overall NO_x emission reductions for the affected boilers totaled about 340,000 tons, i.e. a reduction of 33 percent. In Phase II , approximately 2.06 million tons per year of NO_x reductions are projected to result from the Acid Rain NO_x Program requirements.

Revised NO_x New Source Performance Standards (NSPS) Under the CAA, new power plants are subject to NSPS that represent maximum allowable emission rates and are based upon the best adequately demonstrated technology. EPA promulgated a revised NO_x NSPS for fossil fuel-fired utility and industrial boilers in 1998 (63 FR 49442, September 16, 1998). The new standards revise the NO_x emission limits for steam generating units in subpart Da (Electric Utility Steam Generating Units) and subpart Db (Industrial, Commercial, Institutional Steam Generating Units) and affect only units for which construction, modification, or reconstruction commenced after July 9, 1997. The NO_x emission limit in the final rule for new subpart Da units is 201 nanograms per joule (ng/J) [1.6 lb/megawatt-hour (MWh)] gross energy output regardless of fuel type. For existing sources that become subject to subpart Da through modification or reconstruction, the NO_x emission limit in the final rule was 0.15 lb/million Btu heat input. The estimated decrease in baseline nationwide NO_x emissions is 25,800 tons per year which represents about a 42 percent reduction in growth of NO_x emissions from new utility and industrial steam generating units subject to NSPS. In response to litigation, in December 1999, the EPA voluntarily remanded the limit for existing sources subject to subpart Da through modification or reconstruction. The limit for new sources was upheld by the Court.

III. Compliance Experience

Between 350,000 to 400,000 tons of annual NO_x emissions have been reduced under Phase I of the Acid Rain NO_x Program, and approximately 209,000 tons of annual NO_x emissions have been reduced by eight States under the OTC NO_x Budget Program. (These reductions are not additive, since some units are simultaneously affected by both programs.) Experience over the past four years provides insight into the actual reductions being achieved by the application of different NO_x control technologies. This section examines the compliance options chosen by affected sources, and explores the NO_x emissions reductions under both programs.

NO_x reduction technologies for boilers can be grouped into two categories: combustion controls and post-combustion controls (see Appendix A). Combustion controls -- which include operational modifications, low-NO_x burners (LNBs), gas reburning, and overfire air (OFA) – reduce NO_x formation during the combustion process. Post-combustion controls, which include selective catalytic reduction (SCR) and selective non-catalytic reduction (SNCR), reduce NO_x after it has been formed. The primary technology currently used to meet Acid Rain NO_x Program requirements is LNBs. The OTC NO_x Budget Program requirements are generally met through a mix of combustion controls and post-combustion controls.

1. Acid Rain Program Experience

Under the Acid Rain NO_x Program, an affected source of NO_x emissions has three compliance options. It can comply by (1) meeting the applicable emission limit (i.e., achieving an annual average emission rate lower than the applicable emission limit), (2) averaging its emission rate with other owned sources to achieve the emission limit, or (3) meeting a less stringent Alternative Emission Limit (AEL). To be considered for an AEL, an affected source must establish that it uses the required NO_x control technology designed to meet the applicable emission limit, that the technology was properly designed, installed and operated, and that the unit is still unable to meet the applicable limit. After reviewing the petition submitted by the source, EPA determines whether an AEL is warranted based on analyses of emissions data and information about the NO_x control equipment.

Because Phase I of the program began on January 1, 1996, this evaluation is based on the data currently available for 1996 through 1998.[2,3,4] Table 2 shows the compliance options selected by the affected Phase I sources in each of the years 1996 through 1998. These selections demonstrate that most of the sources complied with the requirements by averaging their emissions. Thus, in general, the owners/operators of affected sources chose to achieve NO_x reductions at units where it was technically easier and/or more cost-effective to do so. The emissions achieved at these units, when averaged with emissions from uncontrolled units, resulted in compliance with the program requirements. Also, as seen in Table 2, very few sources needed AELs to comply with their requirements This indicates that NO_x control technology applications appear to be technically feasible and operating reliably.

Table 2. Compliance options selected by the Phase I sources under the Acid Rain NOx Program

Year	Number of Affected Sources	Number of Sources Choosing to Comply Using:		
		Emission limit	Emissions averaging	AEL
1996	239	46	189	4
1997	265	52	204	9
1998	265	51	204	10

The estimated NO_x reductions achieved through the Acid Rain NO_x Program in the first three years of implementation are shown in Table 3. Since this program does not set a cap on NO_x emissions in tons, the certainty and pattern of NO_x reductions does depend on the utilization of sources. These NOx emissions reductions range from about 340,000 tons from 239 sources in 1996, to 409,321 tons from 265 sources in 1997.

Table 3. Estimated NO_x reductions from 1990 level achieved by Phase I sources.

Year	No. of Affected Sources	NO_x Reduction (tons) from 1990	NO_x Reduction (%) from 1990	Average NO_x Emission Rate (lb/mmBtu)
1996	239	340,000	33.0	0.418
1997	265	409,321	31.8	0.412
1998	265	390,254	29.3	0.409

The reduction in 1998 is lower than that in 1997. Moreover, the reductions appear to be decreasing from 33 percent in 1996 to 29.3 percent in 1998. However, the fewer affected sources in 1996 compared to 1997 and 1998, confounds these observations. In order to examine these reductions on a more common basis, the average emission rate achieved from these sources in the years 1996, 1997, and 1998 is also presented. As seen in this table, while there was a decrease in NO_x emissions reduction, the average emission rate decreases from 0.418 lb/mmBtu in 1996 to 0.409 lb/mmBtu in 1998. As explained in the EPA's 1998 Compliance Report, this can be attributed, in part, to greater power generation, as evidenced by increases in heat input of 3 percent in 1997 and 6 percent in 1998, compared to 1996.

The estimated NO_x reductions in 1998 associated with a given NO_x control technology are shown in Table 4. For dry bottom, wall-fired boilers, Phase I units were employing both LNB and LNB with OFA to achieve average emissions rates of 0.45 lb/mmBtu and 0.47 lb/mmBtu, respectively. Considering that the average emission rate for LNB with OFA is higher than that for LNB, and that the reduction in NO_x emission rates from 1990 is greater for LNB with OFA, it appears that sources with higher uncontrolled emissions employed the use of LNB with OFA. In addition, the majority of dry bottom, wall-fired units that reported the use of no NO_x controls achieved an overall reduction in NO_x emission rates from 1990 rates. In this group of uncontrolled units, over half of the units had a reduction of NO_x emission rates generally between 3 and 15 percent from 1990 rates, a few units had reductions in NOx emission rates greater than 25 percent, and some units had an increase in NO_x emission rates. (Note that the NO_x control technology information is based on reporting by sources, and has not been completely verified. Some of the reported uncontrolled sources could represent controlled sources.) These NO_x reductions from reported uncontrolled sources that possibly combustion modifications alone are achieving substantial NO_x reductions.

Table 4. Phase I NO_x reduction compliance choices

	NO_x Control Technology	No. of Boiler Applications	1998 Average NO_x Emission Rate (lb/mmBtu)	NO_x Reduction from 1990 levels
Dry Bottom, Wall-Fired Units	LNB	66	0.45	44%
	LNB with OFA	21	0.47	48%
Tangentially Fired Units	LNB	44	0.36	43%
	Separated OFA	23	0.37	33%
	LNB with separated OFA	23	0.36	45%

Phase I tangentially fired units, which are employing LNB, separated OFA, and a combination of LNB and separated OFA, are achieving an average emission rate between 0.36 lb/mmBtu and 0.37 lb/mmBtu with these technologies. Like wall-fired boilers, the greatest NO_x emission rate reductions from 1990 levels is achieved with LNB with separated OFA, followed by LNB only, and separated OFA only. Thus, it appears that units with higher uncontrolled emissions employed the use of LNB with overfired air. In addition, the majority of tangentially fired units that reported using no NO_x controls achieved an overall reduction in NO_x emissions rates from 1990 rates. In this group of uncontrolled units, some units had an increase in NO_x emission rates from 1990 rates, and over half of the units had a reduction of NO_x emission rates generally between 4 and 19 percent from 1990 rates. Again, these NO_x reductions from reported uncontrolled sources suggest that possibly combustion modifications alone are achieving substantial NO_x reductions.

The use of emissions averaging and the actual emission rates that combustion controls are achieving indicate that units are comfortably meeting the annual NO_x emissions rates established under Phase I of the Acid Rain Program. Although emission averaging encourages sources to achieve more with combustion controls than strictly meeting the annual limit, these Acid Rain results may not represent what combustion controls are completely capable of achieving. A NO_x trading program, like that discussed below for the OTC, provides an economic incentive (selling NO_x allowances) for a unit to go well beyond its required annual emission limit. As a result, the OTC Program results may provide a better indicator of what performance combustion controls are capable of achieving.

2. OTC NO_x Budget Program Experience

Phase II of the OTC NO_x Budget Program began on May 1, 1999, with the objective of reducing NO_x emissions in twelve northeastern States to attain the NAAQS for ground-level ozone. Unlike the Acid Rain NO_x Program, which uses emissions averaging to ease compliance with the annual emissions limit, the NO_x Budget Program uses inter-facility emissions trading to facilitate cost-effective compliance with a fixed cap on ozone season NO_x emissions. Under this program, an affected source has three primary compliance options. It can comply by (1) emitting at a level commensurate with the unit's allocation, (2) emitting less than the allocation and either banking or selling surplus allowances, or (3) emitting more than the allocation and purchasing additional allowances for compliance. This section examines how the NO_x reductions were generally achieved under the OTC NOx Budget Program, and explores the use of allowance markets as a compliance flexibility mechanism.

Compliance Choices In order to assess the compliance options the sources selected, 1990 ozone season emissions were compared to 1999 ozone season emissions for coal-fired OTC Budget sources that are also Acid Rain units. Only Acid Rain units were examined because the 1990 data was readily available for these sources. The estimated NO_x reductions associated with a given NO_x control technology for coal-fired units in the OTC NO_x Budget Program are shown in Table 5. For dry bottom, wall-fired boilers, OTC units were employing LNB, LNB with overfired air, SNCR, and SCR, with ozone season emissions rates ranging from 0.21 lb/mmBtu to 0.41 lb/mmBtu. As expected, the average ozone season emission rate was lower for the post-combustion control technologies, with SCR achieving the lowest emission rate. In addition, the overall reductions from 1990 emission rates was greatest for the SCR retrofit and the least for LNB retrofits. Although the ozone emission rate for the SCR retrofit was 0.21 lb/mmBtu, the third quarter emission rate was 0.18 lb/mmBtu, which might more accurately reflect the emission rate achieved by the SCR that began full operation in July. Since the unit is comfortably achieving OTC Phase II requirements, the level of reduction achieved by the SCR retrofit may not represent what SCR is capable achieving. Most likely this SCR retrofit will continue to achieve greater NOx reduction once the third phase of the OTC trading program begins.

Table 5. OTC NOx Budget Program compliance choices

	NOx Control Technology	No. of Boiler Applications	1999 Average Ozone Season NO_x Emission Rate (lb/mmBtu)	NO_x Reduction from 1990 Levels
Dry Bottom, Wall-Fired Units	LNB	11	0.41	52%
	LNB with OFA	15	0.38	56%
	SNCR with LNB[a]	8	0.35	66%
	SCR[b]	1	0.18	71%
Tangentially Fired Units	LNB	4	0.33	36%
	Separated OFA	9	0.31	43%
	LNB with separated OFA	21	0.28	59%
	SNCR with LNB	3	0.32	56%
Cyclone Units	SCR	2	0.30	80%
Cell Burner Units	LNB	4	0.42	69%
Wet Bottom, Wall-Fired Units	SNCR/SCR hybrid with FLGR	2	0.65	59%

[a] For 3 units, SNCR began operating in August, 1999.
[b] Reflects time of SCR operation, which began operation after the start of the ozone season, in July, 1999.

For tangentially fired boilers, OTC units are employing LNB, separated overfire air, a combination of LNB and overfired air, and SNCR, with all control technologies achieving average ozone season emission rates of 0.28 lb/mmBtu to 0.33 lb/mmBtu. Like the dry bottom, wall-fired boilers, the higher NO_x emission reductions from 1990 rates is achieved with LNB with over-fired air and SNCR. Thus, it appears that units with higher uncontrolled emissions employed the use of LNB with overfired air and SNCR. For the other category of boilers (cyclone, cell burners, and wet bottom, wall-fired), OTC units are employing LNB, SNCR/SCR hybrid, and SCR with all control technologies achieving average ozone season emission rates of 0.30 lb/mmBtu to 0.65 lb/mmBtu. As expected, SCR achieved the lowest emission rate and the greatest emission rate reduction from 1990 levels. Again, since the unit is comfortably achieving OTC Phase II requirementss, the level of reduction achieved by the SCR retrofit may not represent what SCR is capable achieving and greater NOx reduction is expected in the third phase of the OTC trading program.

Furthermore, for all types of units, the majority of units that reported the use of no NO_x controls achieved overall reductions in NO_x emission rates of between 13 and 24 percent from 1990, and some units achieved reductions over 30 percent. (It should be noted that the NO_x control technology information is based on sources' reporting and is not completely verified. Some of the reported uncontrolled sources could represent controlled sources.) Again, as with Acid Rain Program units, these NO_x reductions from reported uncontrolled sources implies that combustion modifications alone are achieving substantial NO_x reductions.

OTC State Participation While the OTC's multi-State approach to NO_x reductions provides some flexibility for participating States, the uniformity of certain program elements across the State regulations ensures that the region-wide reductions occur in a consistent, enforceable manner. This uniformity has facilitated the development of markets for NO_x allowances, with active trading among participants during the past two years.[5]

Under the 1994 OTC NO_x MOU, the NESCAUM/MARAMA NO_x Budget Task Force developed a "model" trading rule for States in the OTC to use as a template in the development of their own regulations.[6] While the model rule was developed as guidance for State regulatory development, the OTC is State-operated and decentralized by design. States therefore had the option of tailoring individual program elements (such as allocation methodology) to fit State-defined criteria. This feature of the OTC is a notable departure from EPA's prior experience under the SO_2 program, in which the Agency was responsible for developing a set of consistent regulations for all affected sources. Several State program characteristics are shown in Table 6.

Table 6. Program characteristics of participating OTC States

State	Emissions Limits for Affected Units*	Allocation Methodology
CT	Phase II: less stringent of 65% reduction or 0.20 lb/mmBtu. Phase III: less stringent of 75% reduction or 0.15 lb/mmBtu.	• EGU and non-EGU allocation based on heat input • Annual allocation
DE	Phase II: based on either the less stringent of a 65% reduction or 0.20 lb/mmBtu; or, the less stringent of 55% or 0.20 lb/mmBtu (differentiated by counties).	• EGU and non-EGU allocation based on heat input • Allowances for 1999-2002 allocated up front
MA	Phase II: less stringent of 65% reduction or 0.20 lb/mmBtu. Phase III: less stringent of 75% reduction or 0.15 lb/mmBtu	• EGU and non-EGU allocation based on heat input • Annual allocation • Multiple allocation accounts (primary, set-aside, new unit, holding)
NH	Phase II: based on the less stringent of 65% reduction or 0.20 lb/mmBtu for specified counties. RACT for all other counties. Phase III: less stringent of 75% or 0.15 lb/mmBtu for specified counties; less stringent of 55% or 0.20 lb/mmBtu for all others.	• EGU and non-EGU allocation based on heat input • Allowances for 1999-2002 allocated up front
NJ	Phase II: less stringent of 35% reduction or 0.20 lb/mmBtu. Phase III: less stringent of 10% reduction or 0.15 lb/mmBtu.	• EGU and non-EGU allocation based on heat input • Adjusts allocation if the NO_x rate is less than the limit • Additional allocations to new source, incentive, and source growth reserves • Annual allocation
NY	Phase II - inner zone: based on less stringent of 65% reduction or 0.20 lb/mmBtu; outer zone: 55% or 0.20lb/mmBtu; Northern zone: subject to RACT. Phase III - inner and outer zone: based on less stringent of 75% reduction or 0.15 lb/mmBtu; Northern zone: 55%/0.20 lb/mmBtu.	• EGU and non-EGU allocation based on a consensus process • Allowances for 1999-2002 allocated up front
PA	Phase II - inner zone: based on less stringent of 65% reduction or 0.20 lb/mmBtu; outer zone: 55% or 0.20lb/mmBtu. Phase III - inner zone: based on less stringent of 75% reduction or 0.15 lb/mmBtu; outer zone: 55%/0.20lb/mmBtu.	• EGU and non-EGU allocation based on heat input • Allowances for 1999-2002 allocated up front
RI	Three of RI's four plants are required to meet a NO_x emission limit of 9 ppm (~0.03 lb/mmBtu) and the fourth plant is required to meet an emission limit of 3.5 ppm (~0.013 lb/mmBtu).	• EGU and non-EGU allocation based on heat input • Allowances for 1999-2002 allocated up front

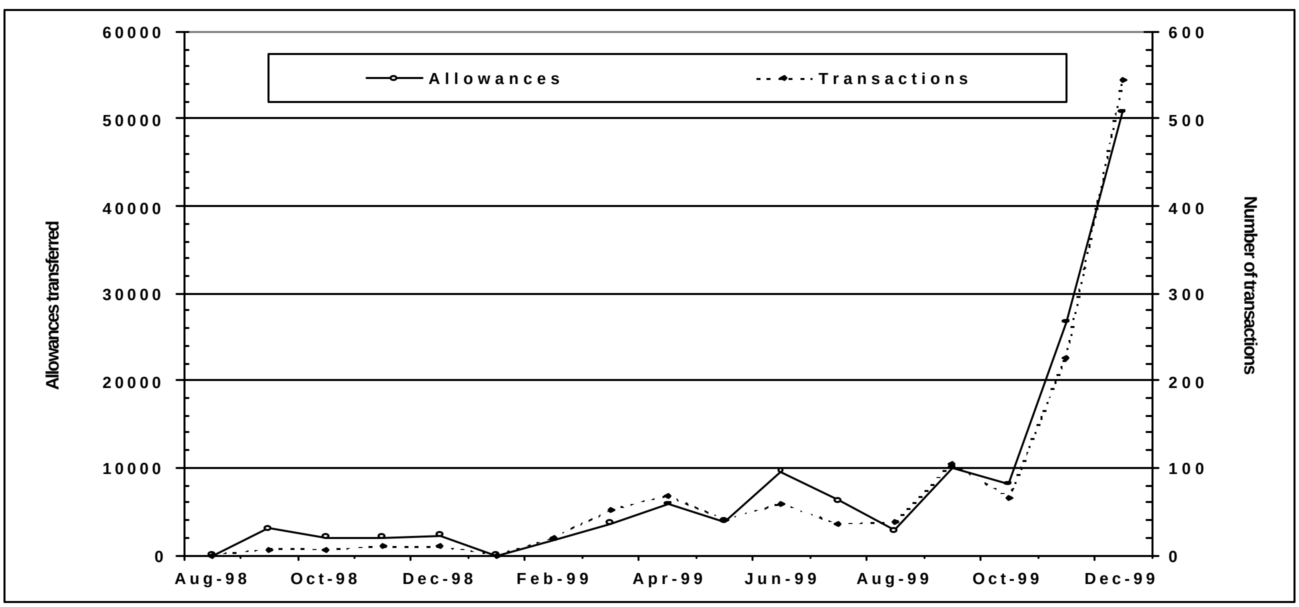
** "Percent reduction" refers to reductions from the 1990 State NO_x emissions baselines, which were established by the OTC Stationary and Area Source Committee, the U.S. EPA, and industry stakeholders.*

Under the conditions of the MOU and the guidance provided by the model rule, each State identified its NO_x budget sources and allocated its allotment of the budget to the sources in the State. These budget sources include a core group of electric generating units with a rated electrical output of 15 MWe or greater, and fossil fuel-fired boilers or indirect heat exchangers with a maximum rated heat input capacity of 250 mmBtu/hour or more. Aside from these requisite budget sources, however, States also had the option of including other source categories (i.e., cement kilns, etc.) in the program. Additional stationary sources of NO_x emissions, designated as eligible by the State, may choose to opt-in on an individual basis. Just as applicability was prescribed in a consistent manner, the OTC seasonal NO_x budget was developed through a uniform process across all twelve States.[7] With the exception of banked allowances retired for compliance, the region-wide ceiling on aggregate emissions cannot be exceeded during the control period; this ensures that the environmental objectives of the program will be achieved. The reductions demanded by the budget, which rely on a combination of combustion and post-combustion controls, would be substantially more burdensome for affected sources in the absence of the accompanying trading program.

Emissions trading Insight into the level and type of allowance trading under the OTC can be gained from data submitted to the NO_x Allowance Tracking System (NATS), which serves as the central registry of allowances used for compliance with the OTC NO_x Budget Program. While NATS was designed primarily for compliance purposes, the system contains details of all reported private allowance transfers. By using data reported to the system, the Agency can follow NO_x allowance movement among affected and unaffected market participants. These details allow EPA to distinguish between a transfer that is a distinct trade between separate entities, and one that is simply for administrative or accounting purposes. This information, used to evaluate unit-level and aggregate transaction activity, offers insight to the degree of compliance flexibility afforded to units subject to the program.

While annual reconciliation for the first ozone control season did not occur until December 31, 1999, brokerages began to report price data for early reduction credits (ERCs) considerably earlier. Through 1,271 private allowance transactions, a total of 138,790 NO_x allowances were transferred between August 1998 and 1999 reconciliation. Figure 1 shows monthly trading volume and transfer activity for all vintages reported to the NATS over this time period. Approximately 40% of these NO_x allowances were transferred between distinct economic entities, rather than within a single operating or holding company. The 543 transfers that shifted these 53,563 allowances are considered economically significant, and provide an indication of overall allowance market activity.[8] The prevalence of these economically significant transactions -- with respect to both total transfers and allowance volume -- indicates that allowances are not merely being shifted across unit accounts within an operating or holding company, but are effectively moving between unaffiliated firms.

Figure 1. OTC NO_x allowance transfers and number of transactions*



* *Allowance transfers were reported by brokerages nearly nine months before the first transfer was recorded in EPA's NATS .*

Of the economically significant volume beginning at the onset of trading, two-thirds of all allowances were purchased by sources of NO_x emissions (utilities, non-utility generators, industrial boilers, fuel suppliers and cogeneration facilities) and nearly three-quarters of all allowances were sold by sources of NO_x. The brokerages and power marketers together comprised the balance of allowance procurement or sales within the market. Of the ten most significant sources as defined by total sales, two (Merrimack and Somerset) made SCR installations in the months preceding the program. Together, these two facilities sold 10,384 allowances, nearly 20% of the total. Trades between distinct firms are not limited to transaction between utilities. While inter-utility transfers comprise the majority of the NO_x allowance movement, interactions involving other affected and non-affected participants account for 13.3 and 21.7 percent of total volume, respectively. Specifically, the significant role of non-utility generators (including Independent Power Producers, Co-Generators, and industrial facilities) is an early and notable feature of the program. Further, the substantial activity by speculators demonstrates the rapid entry and significant role of unaffected players. Table 7 shows the number of allowances traded between different categories of market participants.

Table 7. Economically significant NO_x allowance movement between market participants*

	Buyer						
Seller	Broker	Fuel Sup.	Non-utility	Other	Utility	Total allowances	% of Total
Broker	155	200	1984	0	9307	11646	21.7
Fuel Supplier	156	0	0	0	1252	1408	2.6
Non-utility	1931	341	166	9	3288	5735	10.7
Utility	10015	1353	7247	5	16154	34774	64.9
Total allowances	12257	1894	9397	14	30001	53563	
% of Total	22.9	3.5	17.5	0.0	56.0		

* *Values are the percentage of total economically significant allowance volume, based on the seller.*

While the NO_x allowance market price index (MPI) for vintage 1999 allowances remained relatively stable between September and December 1999, the market for '99's was characterized by wide price swings and considerable volatility during the first nine months of the year.[9] Fluctuations of this magnitude were not anticipated by the engineering or economic forecasts in the integrated planning models, nor were they experienced during the onset of allowance trading under the SO_2 program. While a combination of market conditions and behavioral factors contributed to the dramatic and unpredictable shifts in the '99 allowance price, it is likely the structure of the OTC NO_x Budget Program played a role in fostering volatility.

In particular, the coalition of twelve jurisdictions enacting unique rules -- each subject to a myriad of State-specific circumstances -- exposed the developing allowance market to regulatory and non-regulatory uncertainty. For example, the finalization of several rules less than a year before implementation -- rather than the timely promulgation of these regulations -- likely caused uncertainty about the fate of the proposed program elements. The ambiguity reduced the lead time during which firms could test compliance strategies against the allowance market. For this and other reasons, sources may have turned to last minute allowance purchasing as a alternative to more pre-emptive compliance strategies.

As with the last minute finalization of several State rules, questionable participation by several jurisdictions (including Maryland, DC, and Delaware) led to sudden shifts in perceived demand for NO_x allowances. The litigation in Maryland that stayed PEPCO and BG&E's participation, for example, reduced anticipated demand by an estimated 25,000 allowances; the effect of the decision on the market was an immediate and significant decline in the MPI. While uncertainty often accompanies regulatory development, the multi-State coalition approach is, by design, subject to the additional circumstances affecting each participating State. Since uncertainty spawns volatility, it is not surprising that the MPI has fluctuated broadly over the first year of the OTC NO_x Budget Program.

Perhaps as a consequence of the added uncertainty under a coalition approach, there are indications that sources within the OTC are increasingly using derivative instruments to manage the substantial risks associated with the volatile allowance prices and stiff noncompliance penalties. This activity is common in the context of Title IV's Sulfur Allowance Trading Program, although it developed slowly during the first several years of trading. While EPA is not currently in a position to track or quantify forward market positions in the OTC, the use of these instruments suggests an elevated level of sophistication by certain sources and brokerages.

IV. Conclusions

The NO_x programs under Title I and Title IV have made significant inroads towards emissions reductions in the United States, while simultaneously advancing innovative mechanisms to achieve the mandated reductions in a cost-effective manner. Practical experience with the Acid Rain NO_x Program and the OTC NO_x Budget Program, in particular, offers insight into both the NO_x control selections by sources and actual unit-level emissions reductions.

Annual improvement in the emission rates achieved by NO_x combustion controls, evident during the first three years of the Acid Rain

NO_x Program, have continued into the first year of the OTC. Specifically, reductions in the average emissions rates for tangentially fired and wall-fired boilers with LNB and LNB with overfire air are observed in the first year of the OTC program, relative to 1998 rates under the Acid Rain Program. Reductions by post-combustion controls are also expected to improve over time, and are predicted to build upon the recent improvements with NO_x combustion controls. Currently, under the OTC program, SCR is achieving emission rate reductions between 70 and 80 percent. However, because OTC are comfortably meeting the Phase II requirements, this probably does not represent what SCR is capable of achieving at these units. Future projections for OTC SCR units estimate NO_x emissions reductions over 90 percent.[10] This projection is corroborated by experience in Germany, where the technology has been achieving NOx reductions greater than 90 percent.[11]

Under the Acid Rain NO_x Program, the certainty and pattern of NO_x mass reductions vary from year to year depending on utilization by sources. While it offers certain advantages, a rate-based control program does not achieve the consistent level of NO_x reduction achieved under a firm budget. The cap-and-trade approach under the OTC provides more certainty regarding the limit on aggregate mass emissions over the life of the program, regardless of unit-level emissions rates. Under both programs, flexibility is afforded through the compliance mechanism. As expected, utilities have chosen emissions averaging as the primary compliance option under the Acid Rain Program. The use of this mechanism reflects that, in general, NO_x reductions are achieved at units where it is technically easier and/or more cost-effective to do so. In the OTC, economically significant allowance movement is substantial despite the early volatility in the market price index. This substantial volume implies that high transaction costs do not inhibit efficient allowance movement between firms. More importantly, it suggests that sources effectively use allowance trading to meet the emissions reductions across their units.

V. Acknowledgments

The authors wish to gratefully acknowledge the significant contribution by Ravi K. Srivastava, Air Pollution Prevention and Control Division, National Risk Management Research Laboratory, U.S. EPA, Research Triangle Park, NC. We also thank Peter Tsirigotis, Clean Air Markets Division, Office of Atmospheric Programs, U.S. EPA, Washington, DC.

VI. References

1. *1990 OTC NO_x Baseline Emission Inventory*, Office of Air and Radiation, U.S. Environmental Protection Agency, Washington, D.C., July 1995. (EPA-454/R-95-013)

2. 1996 *Compliance Report*, Office of Air and Radiation, U.S. Environmental Protection Agency, Washington, D.C., June 1997. *www.epa.gov/acidrain/outreach.htm*

3. *1997 Compliance Report*, Office of Air and Radiation, U.S. Environmental Protection Agency, Washington, D.C., August 1998. *www.epa.gov/acidrain/outreach.htm*

4. *1998 Compliance Report*, Office of Air and Radiation, U.S. Environmental Protection Agency, Washington, D.C., August 1999. *www.epa.gov/acidrain/outreach.htm*

5. Early reduction credits were traded during the months preceding the allowance allocations, beginning in December 1997.

6. Northeast States for Coordinated Air Use Management (NESCAUM) and the Mid-Atlantic Regional Air Management Association (MARAMA) NO_x Budget Model Rule, January 1996.

7. The NO_x budget was established by applying the OTC MOU emission reduction targets to each source contributing to the 1990 NO_x emissions baseline. The NO_x budget was then divided among the all OTC states, which allocated allowances to their respective budget sources

8. Since many allowances are held by brokerages on behalf of acquiring electric utilities, EPA's recordation of the number of allowances that utilities have acquired is, at best, an approximation.

9. Market price index (MPI) is derived by averaging the best bid, best offer, and most recent trades.

10. *Public Service of New Hampshire News Release*, November 19, 1998.

11. *Performance of Selective Catalytic Reduction on Coal-Fired Steam Generating Units*, U.S. Environmental Protection Agency, June 1997.

12. *Status Report on NOx Control Technologies and Cost Effectiveness for Utility Boilers*, NESCAUM and MARAMA, June 1998.

Appendix A. Current NO_x Control Technologies

Brief descriptions of commercially available NO_x control technologies for coal-fired electric utility boilers are presented below. The first section describes the prevalent technologies and the following section addresses technologies that are considered to be relatively new or advanced.

1. Widely-Used NO_x Control Technologies

Operational Modifications change certain boiler operational parameters to create conditions in the furnace that will lower NO_x production. Examples are burners-out-of-service, low excess air, biased firing, and optimization software. In burners-out-of-service, selected burners are removed from service by stopping fuel flow, but air flow is maintained to create staged combustion in the furnace. Low excess air involves operating at the lowest possible excess air level while maintaining good combustion, and biased firing involves injecting more fuel to some burners (typically the upper burners) to create staged combustion conditions in the furnace. Optimization software is installed to optimize the combustion process on a real time basis.

Low NO_x Burners (LNB) limit NO_x formation by controlling the stoichiometric and temperature profiles of the combustion process. This control is achieved by design features that regulate the aerodynamic distribution and mixing of the fuel and air, resulting in one or more of the following conditions: (a) reduced oxygen in the primary flame zone, which limits fuel NO_x formation; (b) reduced flame temperature, which limits thermal NO_x formation; and (c) reduced residence time at peak temperature, which limits thermal NO_x formation. LNB can typically achieve NO_x reductions between 30 and 65 percent from uncontrolled levels.

Overfire Air (OFA), also referred to as air staging, is a combustion control technology in which a fraction, 5 to 20 percent, of the total combustion air is diverted from the burners and injected through ports located downstream of the top burner level. OFA is generally used in conjunction with operating the burners at a lower-than-normal air-to-fuel ratio, which reduces NO_x formation. The OFA is then added to achieve complete combustion. OFA can be used in conjunction with LNBs. The addition of OFA to LNB can increase the reductions by an additional 10 to 25 percent.

Natural Gas Reburning (NGR) is a combustion control technology in which part of the main fuel heat input is diverted to locations above the main burners, thus creating a secondary combustion zone called the reburn zone. In NGR, the secondary (or reburn) fuel, natural gas, is injected to produce a slightly fuel rich reburn zone. Completion or overfire air is added above the reburn zone to complete burnout of reburn fuel. As flue gas passes through the reburn zone, part of NO_x formed in the main combustion zone is reduced by hydrocarbon fragments (free radicals) and converted to molecular nitrogen (N_2). In general, NGR is capable of providing 50 to 60 percent NO_x reduction on coal-fired boilers.

Selective Non-Catalytic Reduction (SNCR) is a post-combustion technology in which a reagent (ammonia or urea) is injected into the furnace above the combustion zone, where it reacts with NO_x to reduce it to N_2 and water. SNCR reactions occur in the temperature range of 900 to1100EC. In general, SNCR is capable of providing levels of NO_x reduction ranging from 30 to 60 percent.

Selective Catalytic Reduction (SCR) is a post-combustion NO_x reduction technology in which ammonia is added to the flue gas, which then passes through layers of a catalyst. The ammonia and NO_x react on the surface of the catalyst, forming N_2 and water. SCR reactions occur in a temperature range of 300 to 400°C. In general, SCR is capable of providing high levels of NO_x reduction, ranging from 80 to 90 percent.

2. Recent or Advanced NO_x Control Technologies[12]

Fuel Lean Gas Reburning (FLGR), also known as controlled gas injection, is a process in which careful injection and controlled mixing of natural gas into the furnace exit region reduces NO_x. The gas is normally injected into a lower temperature zone than NGR. Whereas NGR requires 15-20 percent of furnace heat input from gas and requires burnout air, the FLGR technology achieves NO_x control using less than 10 percent gas heat input and no burnout air. Lower NO_x reductions are achieved with FLGR when compared with NGR. FLGR has been demonstrated to reduce NO_x emissions by roughly 33-45 percent at full load, with less than 7 percent of the heat input attributed to the reburn fuel.

Advanced Gas Reburning (AGR) adds a nitrogen rich compound (typically urea or ammonia) downstream of the reburning zone. The reburning system is adjusted for somewhat lower NO_x reduction to produce free radicals that enhance SNCR NO_x reduction. AGR systems can be designed in two ways: 1) non-synergistic, which is essentially the sequential application of NGR and SNCR (i.e., the nitrogen agent is injected downstream of the burnout air); and (2) synergistic, in which the nitrogen agent is injected with a second burnout air stream. To obtain maximum NO_x reduction and minimum ammonia slip in non-synergistic systems, the nitrogen agent must be injected so that it is available for reaction with the furnace gases within a temperature zone around 1000E C. A test done on a 285 MW European boiler showed NO_x reduction between 50 percent (full load) and 70 percent (46 percent load) with an ammonia slip of less than 8 ppm. A synergistic AGR system was demonstrated on a 105 MW utility boiler in New York to reduce NO_x emissions by 68-76 percent. However, it could not reduce ammonia slip to less than 10 ppm.

Amine Enhanced Gas Injection (AEGI) is similar to AGR, except that burn out air is not used, and the SNCR reagent and reburn fuel are injected to create local, fuel-rich NO_x reduction zones in an overall fuel-lean furnace. The fuel-rich zone exists in local eddies, as in FLGR, with the overall furnace in an oxidizing condition. However, the SNCR reagent participates with natural gas (or other hydrocarbon fuel) in a NO_x reduction reaction, which is believed to be different than the reaction that occurs when ammonia or urea are used in SNCR. In SNCR the NO_x reduction occurs in an oxidizing environment, while in AEGI the ammonia or urea is injected into the reducing zone. Preliminary results at a demonstration plant show approximately 73 percent reduction at about 40 percent load, 60 percent reduction at 60 percent load, and 30-40 percent reduction at full load.

Hybrid Selective Reduction (HSR) is a combination of SNCR and SCR that is designed to provide the performance of full SCR with significantly lower costs. In HSR, an SNCR system is used to achieve some NO_x reduction and to produce a controlled amount of ammonia slip that is used in a downstream in-duct SCR reactor for additional NO_x reduction. A test done with this hybrid system showed 95 percent NO_x reduction with less than 5 ppm ammonia slip and 55 percent reagent utilization.